# PUERTO RICO AND VIRGIN ISLANDS PRECIPITATION FREQUENCY PROJECT

Update of *Technical Paper No. 42* and *Technical Paper No. 53*

Twenty-third Progress Report
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Hydrometeorological Design Studies Center
Hydrology Laboratory

Office of Hydrologic Development
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The data and information presented in this report are provided only to demonstrate current progress on the various technical tasks associated with this project. Values presented herein are NOT intended for any other use beyond the scope of this progress report. Anyone using any data or information presented in this report for any purpose other than for what it was intended does so at their own risk

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## 1. Introduction

The Hydrometeorological Design Studies Center (HDSC), Hydrology Laboratory, Office of Hydrologic Development of NOAA's National Weather Service is updating its precipitation frequency estimates for Puerto Rico and the U.S. Virgin Islands. Current precipitation frequency estimates for the area are contained in *Technical Paper No. 42* "Generalized estimates of probable maximum precipitation and rainfall-frequency data for Puerto Rico and Virgin Islands" (U.S. Weather Bureau, 1961) and *Technical Paper No. 53* "Two- to ten-day rainfall for return periods of 2 to 100 years in Puerto Rico and Virgin Islands" (Miller, 1965). The new project includes collecting data and performing quality control, compiling and formatting datasets for analyses, selecting applicable frequency distributions and fitting techniques, analyzing data, mapping and preparing reports and other documentation.

The project will determine annual precipitation frequencies for durations from 5 minutes to 60 days, for average recurrence intervals from 1 to 1,000 years. The project will review and process all available rainfall data for the Puerto Rico and Virgin Island project area and use accepted statistical methods. The project results will be published as a Volume 3 of NOAA Atlas 14 on the internet (http://www.nws.noaa.gov/ohd/hdsc) with the ability to download digital files.

The project area covers Puerto Rico and the U.S. Virgin Islands of St. Thomas, St. John and St. Croix. The project area is currently divided into 9 regional groups for long duration (24-hour through 60-day) analyses (Figure 1) and 4 regional groups for short duration (60-minute through 12-hour) analyses (Figure 2).

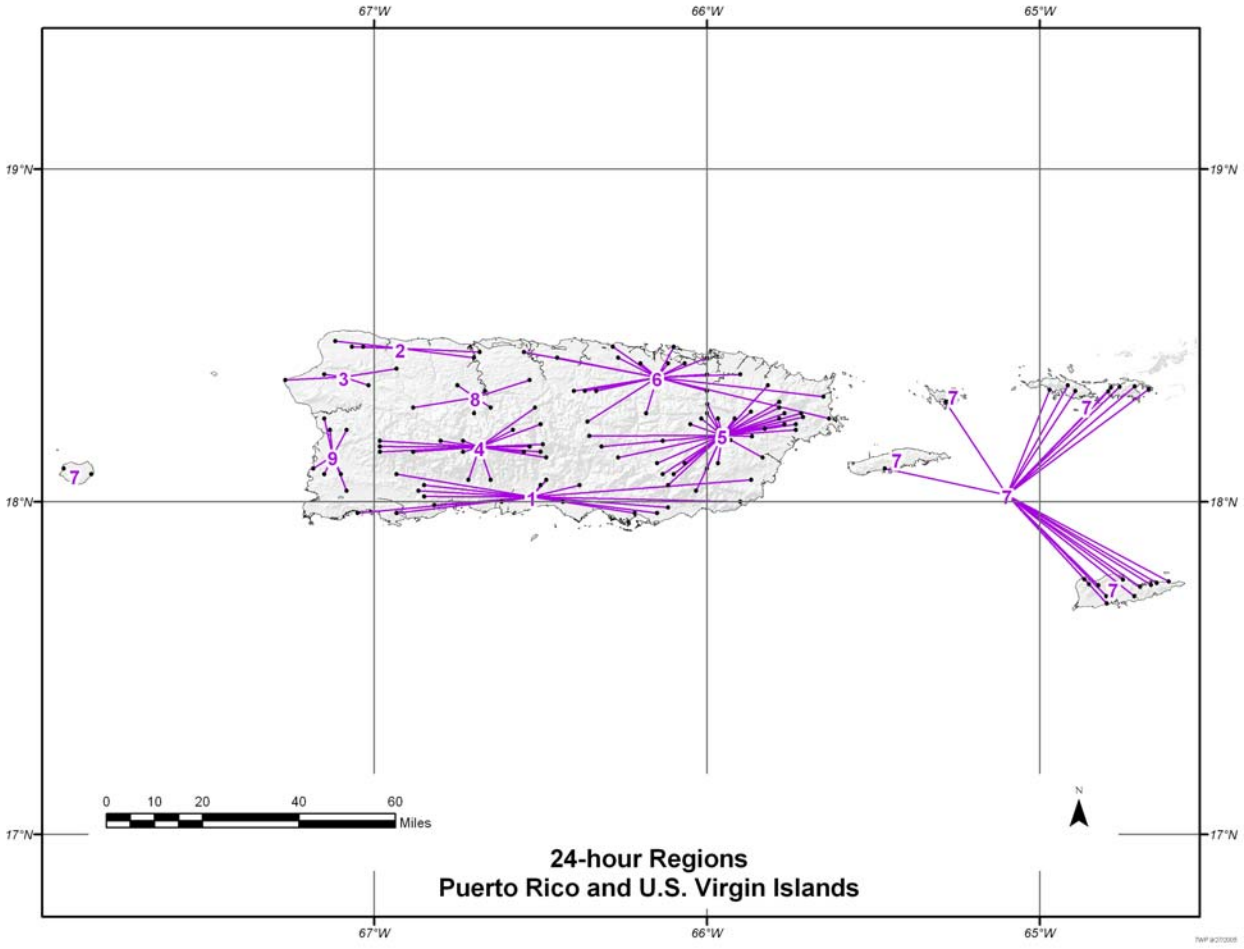


Figure 1. Puerto Rico Precipitation Frequency project area and 9 regional groups based on 24-hour data.

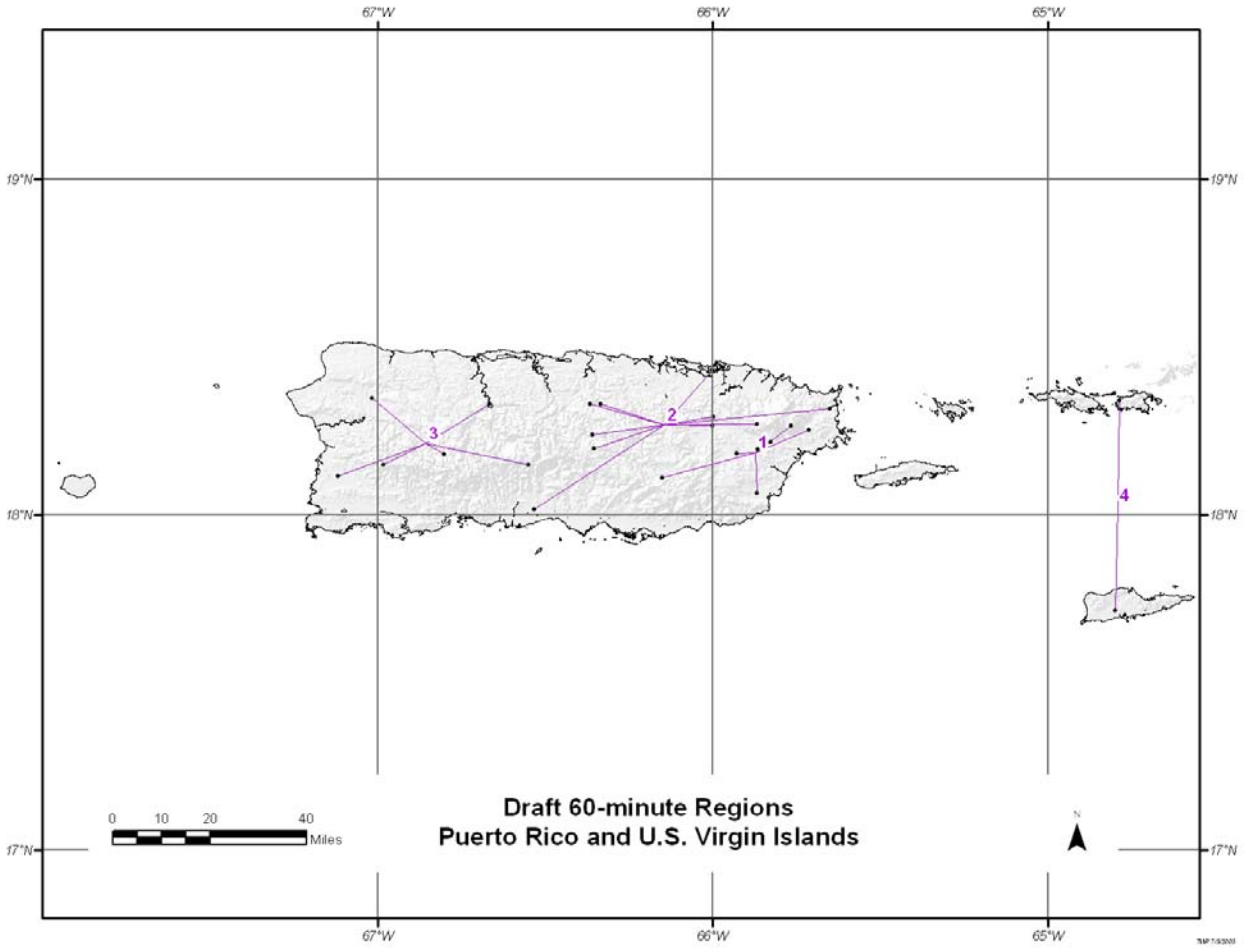


Figure 2. Puerto Rico Precipitation Frequency project area and 4 regional groups based on 60-minute data.

## 2. Highlights

A peer review of the draft results for the Puerto Rico and U.S. Virgin Islands Precipitation Frequency Project concluded on January 11, 2006. The review included the point precipitation frequency estimates and confidence limits for all observing sites and four spatially interpolated maps. Forty-seven unique comments were received and responses to these comments were published on February 15, 2006. Additional information is provided in Section 3.1, Peer Review.

Minor changes were made to correct erroneous data at two stations. We deleted station 66-1142, which was suspected to be anomalously high, based on peer review comments. Additional information is provided in Section 3.2, Data Quality Control.

Confidence limits for the 24-hour duration were modified to better reflect the uncertainty at co-located daily/hourly stations. Additional information is provided in Section 3.3, Confidence Limits.

Final mean annual maximum values were sent to SCAS at Oregon State University for interpolation using PRISM on February 3, 2006. Initial grids of the 60-minute and 24-hour durations were reviewed by HDSC to assess changes in data and enhancements in the PRISM process. Results from SCAS are expected to be received in late April. Additional information is provided in Section 3.4, Spatial Interpolation.

HDSC is investigating a potential Internet Map Server to replace the need for cartographic maps. Additional information is provided in Section 3.5, Internet Map Server.

HDSC continuously monitors the hits, integrity and performance of the Precipitation Frequency Data Server (PFDS), the on-line portal for all NOAA Atlas 14 deliverables and information. Additional information is provided in Section 3.6, PFDS.

Six additional rain gauge networks have either been added or are being considered to the growing list of ARF study areas across the United States. Although ARF software development has been slow, several milestones have been reached. Additional information is provided in Section 3.7, Areal Reduction Factors.

# 3. Progress in this Reporting Period

## 3.1 Peer Review

A peer review of the draft results for the Puerto Rico and U.S. Virgin Islands Precipitation Frequency Project concluded on January 11, 2006. The review included point and spatially distributed precipitation frequency estimates, as well as temporal and trend analysis reports.

HDSC requested comments from approximately 115 individuals and received comments from 14 individuals. Some of the responses represented feedback from their staff. Forty-seven unique comments were received and required responses. Some comments were editorial in nature and some required a more complete explanation. Others prompted the re-examination and validation of results. One comment in particular lead to an important data correction (see Section 3.2 Data Quality Control). HDSC completed a document that presents a consolidation of all the review comments collected during the 10-week review period and HDSC's response. The original wording of the comments was used to make sure the meaning of the comment/question was not misconstrued and so that individual reviewers can identify their comments. This formal response was distributed on February 15, 2006 and is available at http://hdsc.nws.noaa.gov/hdsc/pfds/pr/prvi_peer_review_response_final.pdf.

HDSC thanks all who participated in the review. Several critical questions were answered by local experts that will strengthen the validity and accuracy of the final product.

## 3.2 Data Quality Control

Erroneous data were corrected at two stations. At station 66-1301 (Caguas 2 ENE), a 2 day accumulation was mis-entered as a 1-day value (18.00 inches occurred over two days, September 13-14, 1928, according to original observation forms). The change creates consistency with nearby stations. At station 66-7295 (Ponce City) two annual maximums were found to be anomalously low compared to annual maximums at nearby stations for those years. The years 1996 and 1998 (where 60-day values were less than 3 inches) were set to missing because the data records were missing critical months in those years which erroneously lowered the extracted maximum.

Station 66-1142 (Cacaos-Orocovis), in central Puerto Rico, had long been suspected of being anomalously high compared to nearby stations but no objective evidence could be found to discredit the data. Peer review comments led to the removal of 66-1142 from the analysis. Based on their knowledge of the local climate, the reviewers felt it was not reasonable for it to have such significantly higher rainfall than its neighboring stations. They also uncovered that during some portion of the lifetime of the station, the observer had a tarp that drained toward the rain gauge, which of course could result in some bias. The impact of removing the station on the remaining stations in the region

(daily region 4) was minimal. The region was still homogeneous and 100-year and 1,000-year 24-hour estimates decreased by less than 1% and 1.5%, respectively.

HDSC documents and forwards data errors to NCDC to ensure the results of our quality assurance efforts are available to future users of the NCDC archives.

### 3.3 Confidence Limits

Confidence limit algorithms for the 24-hour duration were modified to better reflect the uncertainty at co-located daily/hourly stations. The 24-hour confidence limits are now obtained from the analysis of the daily regions that have a larger sample size, instead of the hourly regions at co-located stations. This has decreased the band of uncertainty at most co-located stations and more accurately reflects the uncertainty associated with the quantile derived from the daily region.

### 3.4 Spatial Interpolation

On February 3rd, 2006 the final station mean annual maximum values, for all durations, were provided to the Spatial Climate Analysis Service (SCAS) at Oregon State University where PRISM will be used to create high-resolution (3-second) interpolated grids. On March 13, 2006 SCAS provided HDSC with interim updated 24-hour and 60-minute grids for review. These, as well as HDSC-derived 100-year grids/maps, were subjected to internal review. The internal review focused on several issues raised during the peer-review, changes because of enhancements to the PRISM modeling configuration, and changes in the HDSC-calculated mean values. Overall, results seemed reasonable and consistent with expectations. The most significant changes were:

60-minute means:

- Overall, less spatial smoothing has allowed spatial patterns to better reflect terrain-influencing details. For instance, a trough of lower values now extends from the coast southward towards Dos Bocas, PR (66-3431) whereas before higher values were spread across the entire valley area.

- The values west and northwest of Yabucoa, PR (66-9829) are now higher and better reflect the heavy orographically-enhanced precipitation this area receives.

- Values along the entire northern coast dropped slightly and the low values around San Juan, PR now extend further west.

24-hour means:

- Overall, less spatial smoothing has allowed spatial patterns to better reflect terrain-influencing details. For instance, the terrain effects around the northeast mountains of Puerto Rico are more defined and detailed.

- Meteorologists at the National Weather Service Forecast Office (NWSFO) in San Juan indicated that the heavy precipitation at Cacaos-Orocovis (66-1142), in central Puerto Rico, was in error during periods of its record, so it was removed from the database. Prior to its removal, 66-1142 registered the highest 24-hour mean annual maximum of 8.7" in the study area, so its omission triggered a decrease in the 24-hour means in the area. It also caused a southern shift in the maximum 24-hour values which is more consistent with the terrain and climate patterns.

- The improbable area of maximum precipitation over the "hill" northeast of Guayabal, PR (66-4162) was mitigated and now better reflects the precipitation regime in this area.

SCAS will provide final mean annual maximum grids to HDSC during the next quarter (late April). Thereafter, HDSC will derive the entire suite of final precipitation frequency grids/maps using the Cascade Residual Add-back (CRAB) procedure.

### 3.5 Internet Map Server

HDSC is investigating potential Internet Map Servers (IMS) to replace the need for cartographic maps. An IMS would allow a user to create a map of the desired average recurrence interval and zoom in on an area of interest. Cartographic maps of key durations and frequencies will still be produced but the entire suite of all possible duration and frequency combinations (as many as 540 maps) may not be produced. It remains to be determined if or when the IMS would be implemented as part of the final deliverables.

### 3.6 PFDS

HDSC continuously monitors the hits, integrity and performance of the Precipitation Frequency Data Server (PFDS), which continues to receive a steady number of hits per month. The graph in Figure 3 below summarizes the number of individual data inquires made since October 2004, while the map in Figure 3 indicates the locations of inquires during the past quarter.

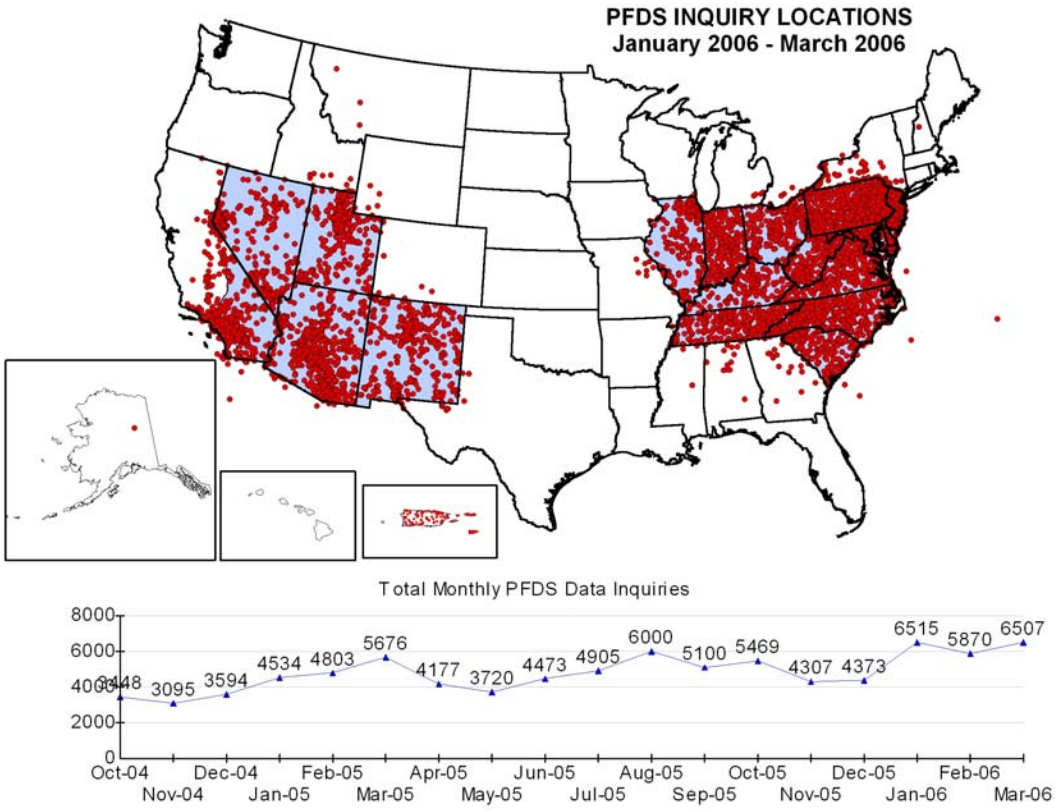


Figure 3: Map of 18,892 PFDS data inquiry locations during the period January-March 2006.

### 3.7 Areal Reduction Factors

Work continues in the development of geographically-fixed Areal Reduction Factors (ARFs) for area sizes of 10 to 500 square miles and durations of 30-minutes to 48-hours for the United States. The results of this supplementary study will be applicable to all volumes of NOAA Atlas 14.

Although ARF software development has been slow, several milestones have been reached. The continuing goal is to develop ARF software based on the NOAA Technical Report NWS 24 (Myers and Zehr, 1980) methodology and obtain the same results published in TR-24 for the Chicago rain gauge network, then apply the methodology to the new study areas we have assembled. The ARF computations are a function of six variables that vary in time and space. Fitting functions (curves) to these six variables so that the results reproduce those in TR-24 has been difficult. Five of the six variables have been successfully coded and produce values very similar to those published in TR-24. The ARF software is expected to be completed during the next quarter.

Six additional rain gauge networks either have been added to or are being considered for the growing list of ARF study areas across the United States. They are located in/near:

- Los Alamos, NM
- Harris County, TX
- Melbourne, FL
- South-central Washington State
- Louisville, KY
- Portland, OR

Figure 4 shows the locations of all rain gauge networks to be used, those rejected as unsuitable and those still under consideration. Meanwhile, Table 1 provides additional details of the preliminary study areas. HDSC will no longer actively seek additional networks. However, efforts to find adequate networks in Alaska, Puerto Rico and Hawaii continue.

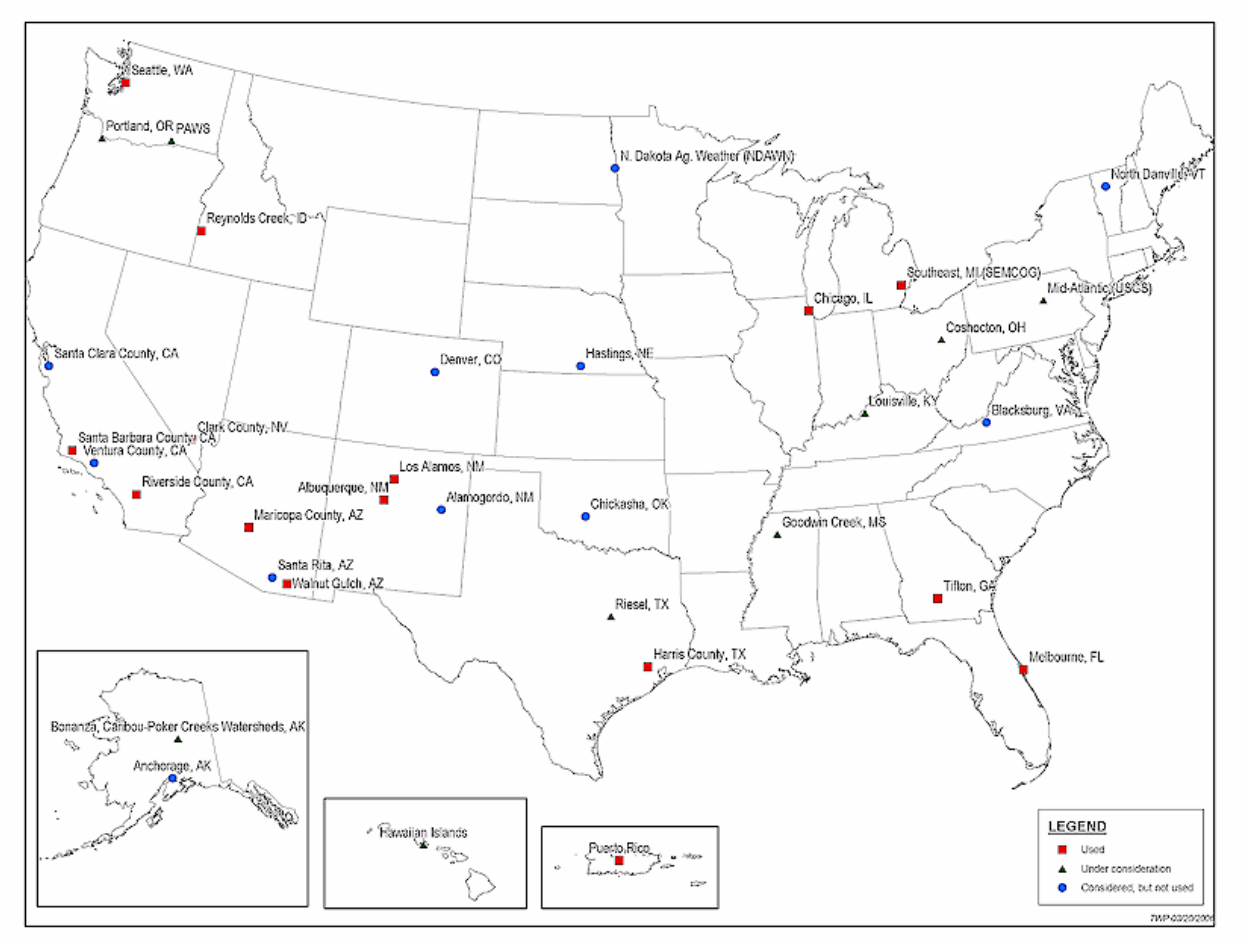

Figure 4. Map of ARF study areas.

Table 1. Preliminary ARF study areas.

| Study area location | Included | Date range | ~Size (sq-mi) | Stations | Lat* | Lon* | Elev. *(ft) |
|---|---|---|---|---|---|---|---|
| Albuquerque, NM | Yes | 1978-1992 | 400 | 13 | 35.161 | -106.566 | 5311 |
| Chicago, IL | Yes | 1949-1980 | n/a | 18 | 41.830 | -87.692 | 618 |
| Clark County, NV | Yes | 1990-2004 | n/a | 48 | 36.290 | -114.978 | 940 |
| Los Alamos, NM | Yes | 1990-2005 | 150 | 9 | 35.858 | -106.282 | 7011 |
| Maricopa county, AZ | Yes | 1980-2001 | n/a | 31 | 33.789 | -112.303 | 2572 |
| Reynolds Creek, ID | Yes | 1962-1996 | n/a | 44 | 43.169 | -116.769 | 5342 |
| Riverside county, CA | Yes | 1961-2001 | n/a | 45 | 33.793 | -116.995 | 1987 |
| Santa Barbara, CA | Yes | 1968-2003 | n/a | 38 | 34.590 | -119.957 | 1203 |
| Seattle, WA | Yes | 1978-2003 | 216 | 23 | 47.553 | -122.333 | 152 |
| South-central Washington state (PAWS) | Yes | 1989-2005 | 700 | 15 | 46.071 | -119.306 | 765 |
| Southeast Michigan (SEMCOG) | Yes | 1988-2002 | n/a | 50 | 42.518 | -83.286 | 730 |
| Melbourne, FL | Yes | 1997-2005 | 450 | 35 | 28.545 | -80.634 | 0 |
| Harris County, TX | Yes | 1997-2005 | 3800 | 165 | 29.779 | -95.405 | n/a |
| Walnut Gulch, AZ | Yes | 1954-1996 | n/a | 107 | 31.728 | -110.024 | 4656 |
| Chickasha (Micronet), OK | Maybe | 1994-2005 | 1130 | 44 | 34.885 | -98.075 | 398 |
| Coshocton, OH | Maybe | 1940-2001 | n/a | 22 | 40.435 | -81.799 | 1044 |
| Goodwin, MS | Maybe | 1981-1996 | n/a | 32 | 34.232 | -89.914 | 333 |
| Jefferson County, KY | Maybe | 1991-2005 | n/a | 18 | 38.190 | -85.670 | n/a |
| Portland, OR | Maybe | 1976-2005 | 200 | 45 | 45.537 | -122.662 | n/a |
| Tifton, GA | Maybe | 1968-1981 | n/a | 55 | 31.439 | -83.590 | n/a |
| Ventura, CA | Maybe | n/a | n/a | 134 | 34.370 | -119.067 | n/a |
| Bonanza, Caribou-Poker Creeks Watershed(s), AK | Maybe | n/a | 50 | n/a | 64.750 | -148.230 | 1641 |
| Puerto Rico (eastern) | Maybe | 1973-2003 | 500 | 10-18 | 18.260 | -65.910 | 800 |
| Hawaii | Maybe | ~1948-2005 | n/a | n/a | n/a | n/a | n/a |
| Alamogordo Creek, NM | No | 1955-1962 | 67 | 64 | 34.920 | -104.143 | 4898 |
| Blacksburg, VA | No | n/a | n/a | <10 | 37.250 | -80.417 | n/a |
| Denver, CO | No | n/a | n/a | n/a | 39.750 | -105.000 | n/a |
| Ft. Collins, CO | No | 1999-2005 | 12 | | 40.567 | -105.093 | 5099 |
| Riesel, TX | No | n/a | 10 | 39 | 31.482 | -96.880 | 544 |
| Hastings, NE | No | 1938-1967 | n/a | 19 | 40.255 | -98.376 | n/a |
| North Danville, VT | No | 1958-1975 | n/a | 27 | 49.678 | -74.724 | 2118 |

* Denotes average central location of study area

## 4. Issues

### 4.1 Past and Upcoming Meetings

On February 2nd HDSC met with Dan Cooley (Colorado State University (CSU), National Center for Atmospheric Research), Richard Davis (CSU), and Richard Smith (University of North Carolina) to discuss research on a Bayesian approach to precipitation frequency analysis and possible collaborative research.

On March 30th the Office of Hydrologic Development hosted a half-day workshop for Chinese delegates from Hohai University in Nanjing, China. HDSC participated and initiated a discussion on precipitation frequency analysis and practical consistency adjustment techniques in hopes of fostering collaborative research.

### 4.2 Update to NOAA Atlas 14 Volumes 1 and 2

The precipitation frequency estimates for the semiarid southwest United States published as Volume 1 of NOAA Atlas 14 and for the Ohio River basin and surrounding states published as Volume 2 of NOAA Atlas 14 will be updated in the near future to incorporate technical enhancements and minor data/analysis corrections. 1-year precipitation frequency estimates will also be released at that time. Careful evaluation of each possible enhancement and correction is underway. The enhancements result from peer reviews and lessons learned in Volumes 2 and 3. They include improved spatial interpolation when using the inverse-distance-weighting function, improved consistency adjustments for co-located daily and hourly stations and for hourly-only stations, and an improvement to the 24-hour confidence limits. Difference maps of the previous versions and the updated versions will be provided. An Addendum will be made available to provide additional details of the changes.

### 4.3 California Precipitation Frequency Project

The state of California and others have verbally committed to funding a project to update the precipitation frequency estimates for the remaining portion of California not covered by NOAA Atlas 14, Volume 1. Agencies involved include CA Department of Transportation, CA Department of Water Resources, NOAA Coastal Storms Program, and U.S. Army Corps of Engineers. A Memorandum of Understanding is being written. Geoffrey Bonnin, Director of HDSC, attended a fruitful meeting in Sacramento California on March 23rd, 2006 to discuss the details with the State and other interested parties.

## 5. Projected Schedule and Remaining Tasks

The following list provides a tentative schedule with completion dates. Brief descriptions of tasks to be worked on are also included in this section.

Peer Review of Spatially Interpolated Point Estimates [Complete]
Spatial Interpolation of Grids [May 2006]
Precipitation Frequency Maps [July 2006]
Web Publication [May 2006]
Spatial Relations (Areal Reduction Factors) [October 2006]

### 5.1 Spatial Interpolation

SCAS is expected to provide the final mean annual maximum grids for all durations in late April. Once HDSC receives the grids, the final precipitation frequency grids will be generated and internally reviewed in as timely a manner as possible.

### 5.2 Areal Reduction Factors (ARF)

Computations for the ARF curves will be completed for 14 areas. The resulting curves will be tested for differences to determine if a single set of ARF curves is applicable to the entire U.S. or whether curves vary by region.

## References

Arkell, R.E., and F. Richards, 1986: Short duration rainfall relations for the western United States, *Conference on Climate and Water Management-A Critical Era and Conference on the Human Consequences of 1985's Climate*, August 4-7, 1986. Asheville, NC.

Bell, F.C., 1976: The areal reduction factors in rainfall frequency estimation, *Natural Environmental Research Council (NERC), Report No. 35*, Institute of Hydrology, Wallingford, U.K. 25pp.

Bonnin, G., D. Todd, T. Parzybok, B. Lin, D. Riley, and M. Yekta, 2004: Precipitation frequency atlas of the United States. *NOAA Atlas 14 Volume 1*, Silver Spring, Maryland. http://hdsc.nws.noaa.gov/hdsc/.

Carter, M. M. and J. B. Elsner, 1996: Convective Rainfall Regions of Puerto Rico, *International Journal of Climatology*, **16**, pp. 1033-1043.

Carter, M. M., S. Bennett, and J.B. Elsner, 1997: Monthly Rainfall Climatology for Puerto Rico, *NWS Southern Topics February 1997*.

Chow, V.T., D.R. Maidment, and L.W. Mays, 1988: Applied Hydrology. McGraw-Hill International Editions, 572 pp.

Colon, J, 1966: On the Mechanisms for Production of Rainfall in Puerto Rico, Weather Bureau *Technical Memorandum 15*, San Juan, Puerto Rico.

Daly, C., W.P. Gibson, G.H. Taylor, G.L. Johnson, and P.Pasteris, 2002: A knowledge-based approach to the statistical mapping of climate. *Climate Research*, **23**, 99-113.

Daly, C., R.P. Neilson, and D.L. Phillips, 1994: A Statistical-Topographic Model for Mapping Climatological Precipitation over Mountainous Terrain. *Journal Applied. Meteorology*, **33**, 140-158.

Frederick, R.H. and J.F. Miller, 1979: Short Duration Rainfall Frequency Relations for California, Third Conference on Hydrometeorology, August 20-24, 1979. Bogata Columbia.

Frederick, R.H., V.A. Myers and E.P. Auciello, 1977: Five- to 60-minute precipitation frequency for the eastern and central United States, *NOAA Technical Memo. NWS HYDRO-35*, Silver Spring, MD, 36 pp.

Hershfield, D.M., 1961: Rainfall frequency atlas of the United States for durations from 30 minutes to 24 hours and return periods from 1 to 100 years, *Weather Bureau Technical Paper No. 40*, U.S. Weather Bureau. Washington, D.C., 115 pp.

Himmelblau, D.M., 1970: "Sign Test for Median Difference in Paired Observations", *Process Analysis by Statistical Methods*, page 68.

Hosking, J.R.M. and J.R. Wallis, 1997: *Regional frequency analysis, an approach based on L-moments*, Cambridge University Press, 224 pp.

Huff, F. A., 1990: Time Distributions of Heavy Rainstorms in Illinois, *Illinois State Water Survey*, Champaign, 173, 17pp.

Institution of Engineers, Australia, 1987: *Australian Rainfall and Runoff, 3rd Edition*, The Institution of Engineers, Australia. Canberra.

Lin, B. and L.T. Julian, 2001: Trend and shift statistics on annual maximum precipitation in the Ohio River Basin over the last century. Symposium on Precipitation Extremes: Prediction, Impacts, and Responses, 81st AMS annual meeting. Albuquerque, New Mexico.

Lin, Shao-Gong, 1980: *Basic Probability and Statistics*. People's Education Publisher, Beijing, China, 162 pp.

Maidment, D. R., 1993: *Handbook of Hydrology*. McGraw-Hill Publishing, 29.47 pp.

Malgren, B., and A. Winter, 1999: Climate Zonation in PR based on Principal Component Analysis and an Artificial Neural Network, *Journal of Climate*, **12**, pp. 977-985.

Miller, J.F., 1964: Two- to ten-day precipitation for return periods of 2 to 100 years in the contiguous United States, *Technical Paper No. 49*, U.S. Weather Bureau and U.S. Department of Agriculture, 29 pp.

Miller, J.F., 1965: Two- to Ten-Day Rainfall for Return Periods of 2 to 100 Years in Puerto Rico and the Virgin Islands, *Technical Paper No. 53*, U.S. Weather Bureau and U.S. Department of Agriculture, 35 pp.

Miller, J.F., R.H. Frederick and R.J. Tracy, 1973: Precipitation-frequency atlas of the western United States, *NOAA Atlas 2*, 11 vols., National Weather Service, Silver Spring, MD.

Myers, V.A. and R.M. Zehr, 1980: A Methodology for Point-to-Area Rainfall Frequency Ratios, *NOAA Technical Report NWS 24*, Office of Hydrology, National Weather Service, Silver Spring, MD.

Newbold, P., 1988: *Statistics for Business and Economics*. Prentice Hall, 866 pp.

Spiegel, M.R., 1961: "Tests of Significance Involving Sample Differences", *Theory and Problems of Statistics*, pages 170-171.

U.S. Weather Bureau, 1961: Generalized Estimates of Probable Maximum Precipitation and Rainfall-Frequency Data for Puerto Rico and Virgin Islands for Areas to 400 Square Miles, Durations to 24 Hours and Return Periods from 1 to 100 Years, *Technical Paper 42*, Washington, DC, 94pp.